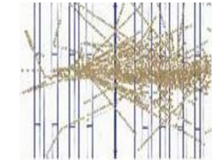

Gamma-ray Induced Radiation Damage up to 340 Mrad in Various Scintillation Crystals

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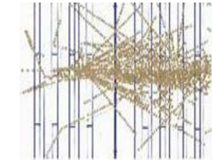
California Institute of Technology

May 19, 2016

Talk in the XVII International Conference on Calorimetry in Particle Physics, Daegu

Introduction

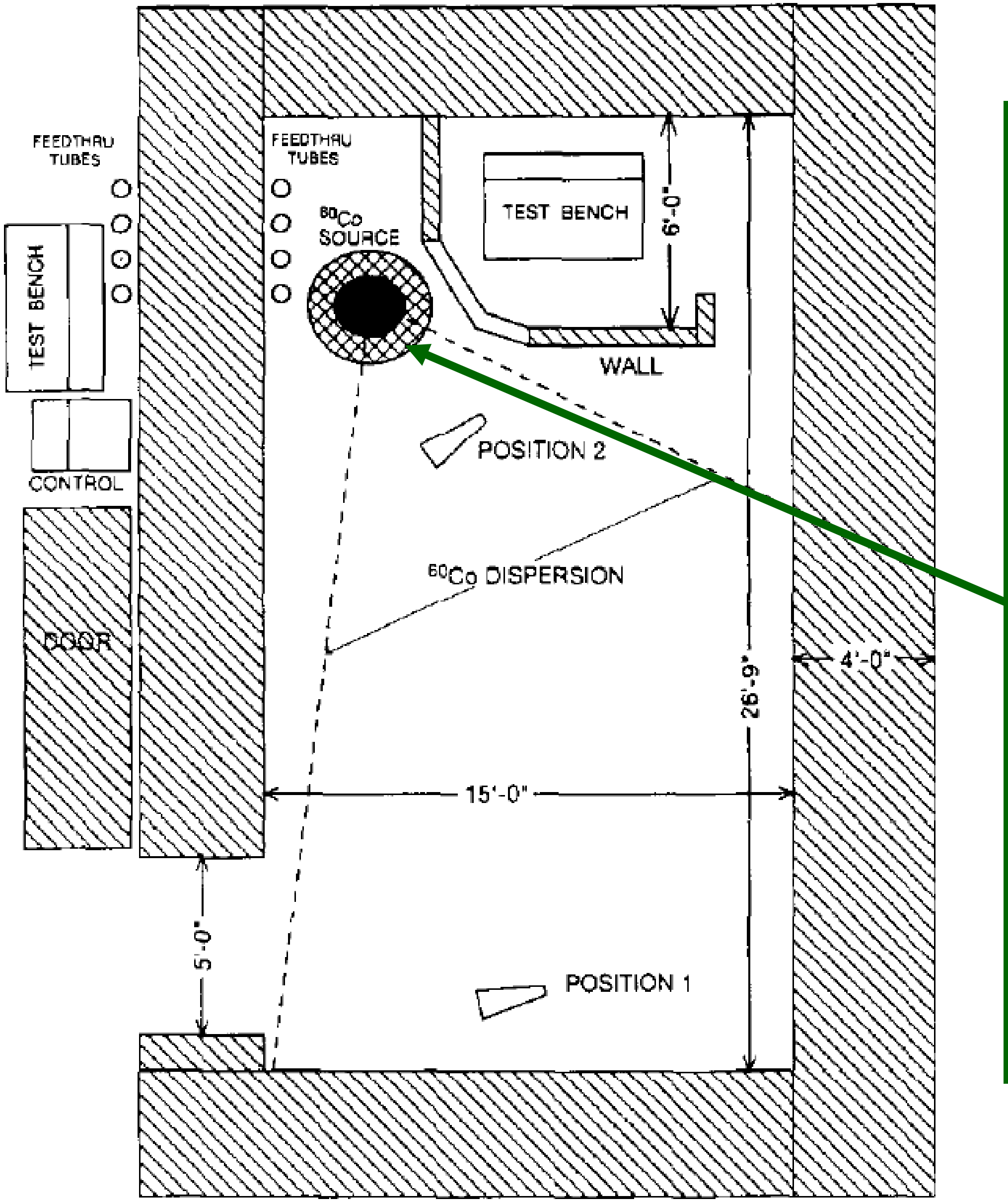


- Gamma-ray induced radiation damage in large size crystal scintillators was investigated for BaF_2, BGO, CeF_3, pure CsI, LSO/LYSO/LFS and PWO.

- Irradiations were carried out at the total ionization dose (TID) facility of Jet Propulsion Laboratory (JPL) up to 340 Mrad with a dose rate up to 1 Mrad/h.

- Long crystal samples were hosted in an aluminum box of ten inch square. The box was inserted in a square throat of 10” x 10” x 13.5” facing a group of Co-60 ɣ-ray sources. The entire body of crystals was uniformly irradiated.

JPL Total Absorption Dose Facility

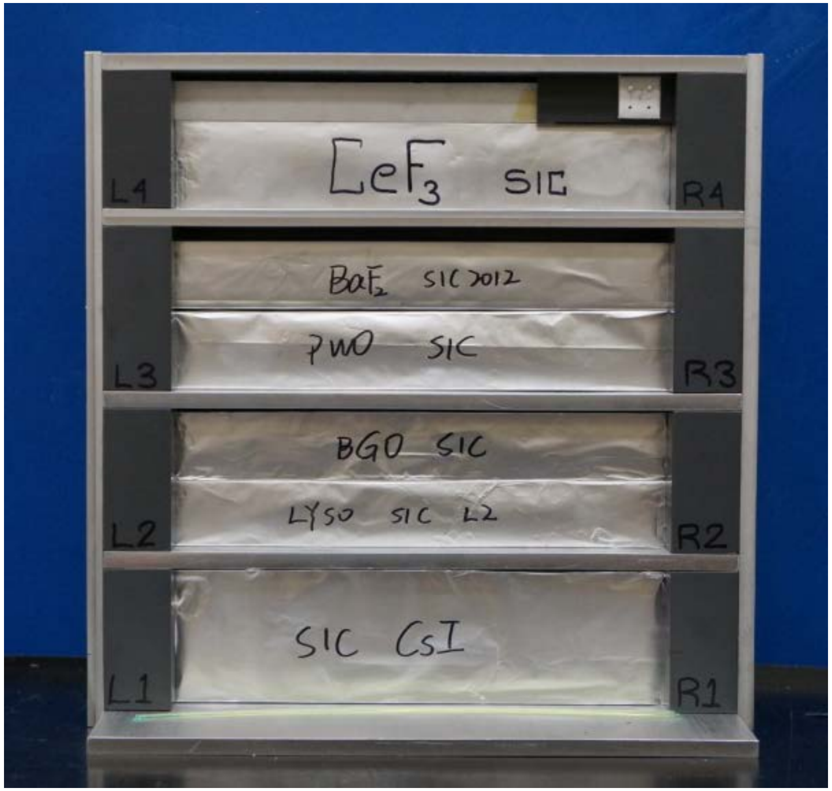


A group of high intensity ^{60}Co sources provides a variable dose rate up to 1 Mrad/h in an opening throat of 10” x 10” x 13.5”.

Irradiation was carried out in step: 10 Mrad first, followed by several 100 Mrad steps over weekends.

The time between the end of each irradiation and the measurements at Caltech is less than 30 minutes.

Crystals Irradiated at JPL



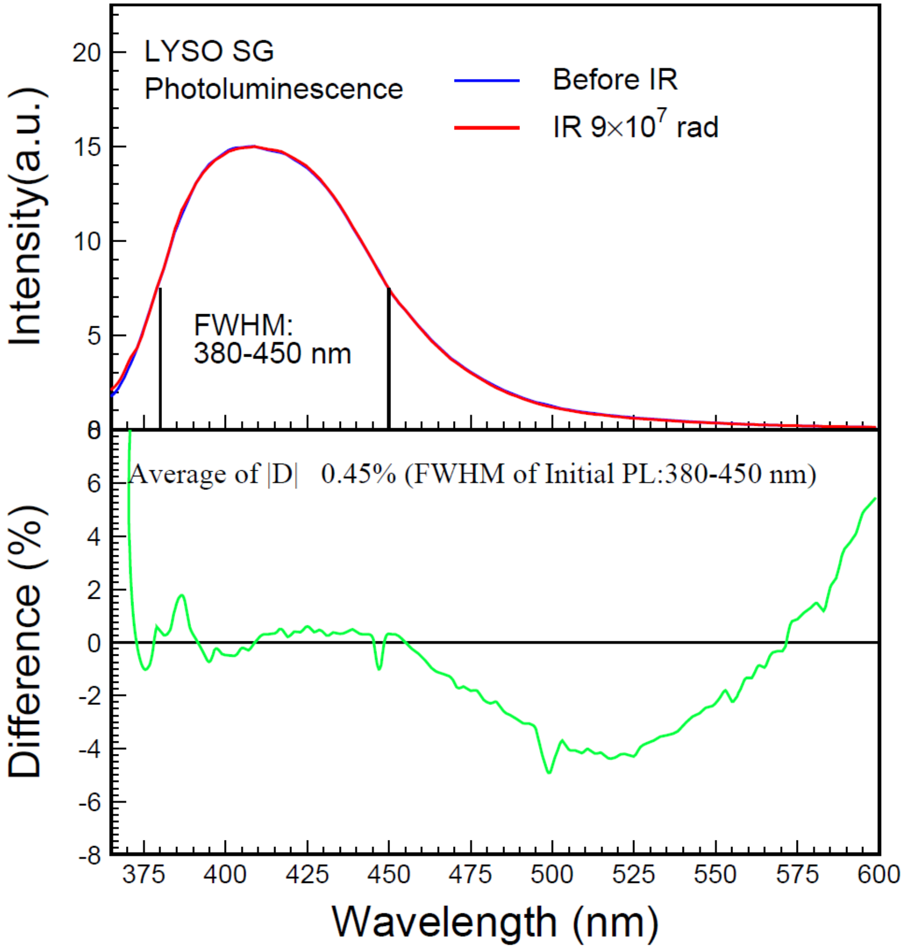
ID	Dimension (mm)
CeF_3	33×32×191
BaF_2	20×20×250
PWO	$28.5^2 \times 30^2 \times 220$
BGO	25×25×200
LYSO	25×25×200
Pure CsI	50×50×200

Experiments

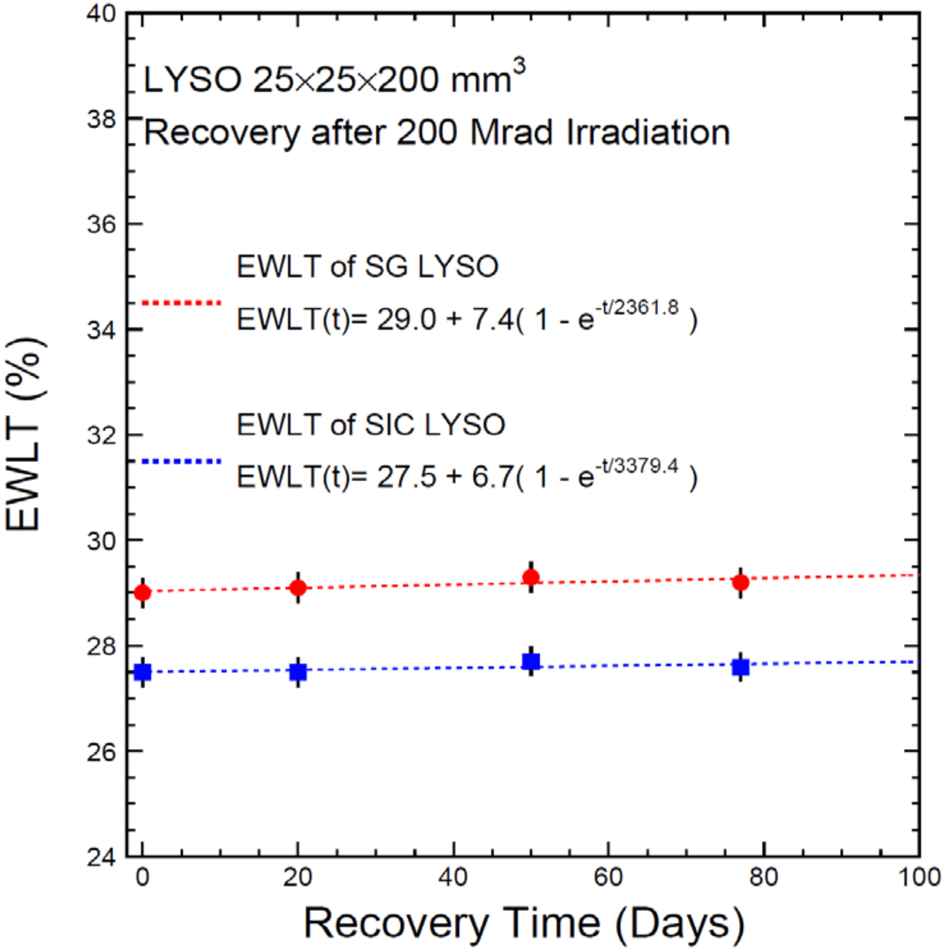
Longitudinal Transmittance (LT) and Light Output (LO) were measured at room temperature before and after each irradiation step.

Gamma-Ray Induced Damage in 20 cm Long LYSO/LSO Crystals

No damage in scintillation mechanism



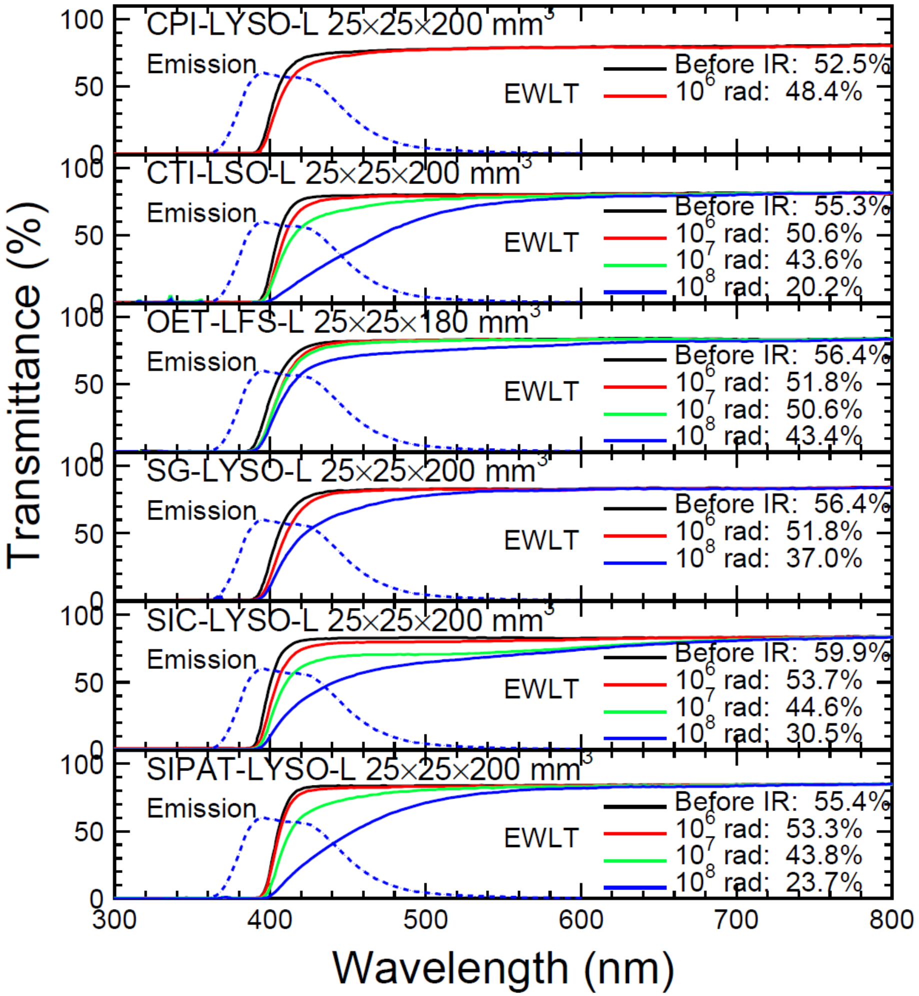
No recovery: dose rate independent



Radiation damage in BaF_2 and pure CsI is also dose rate independent

LYSO/LSO/LFS: Radiation Damage in Longitudinal Transmittance (LT)

The best sample: 77% EWLT after 100 Mrad



EWLT or emission weighted longitudinal transmittance is defined as:

$$\mathrm{EWLT} = \frac{\int \mathrm{LT}(\lambda)\mathrm{Em}(\lambda)d\lambda}{\int \mathrm{Em}(\lambda)d\lambda}$$

RIAC or radiation induced absorption coefficient is defined as:

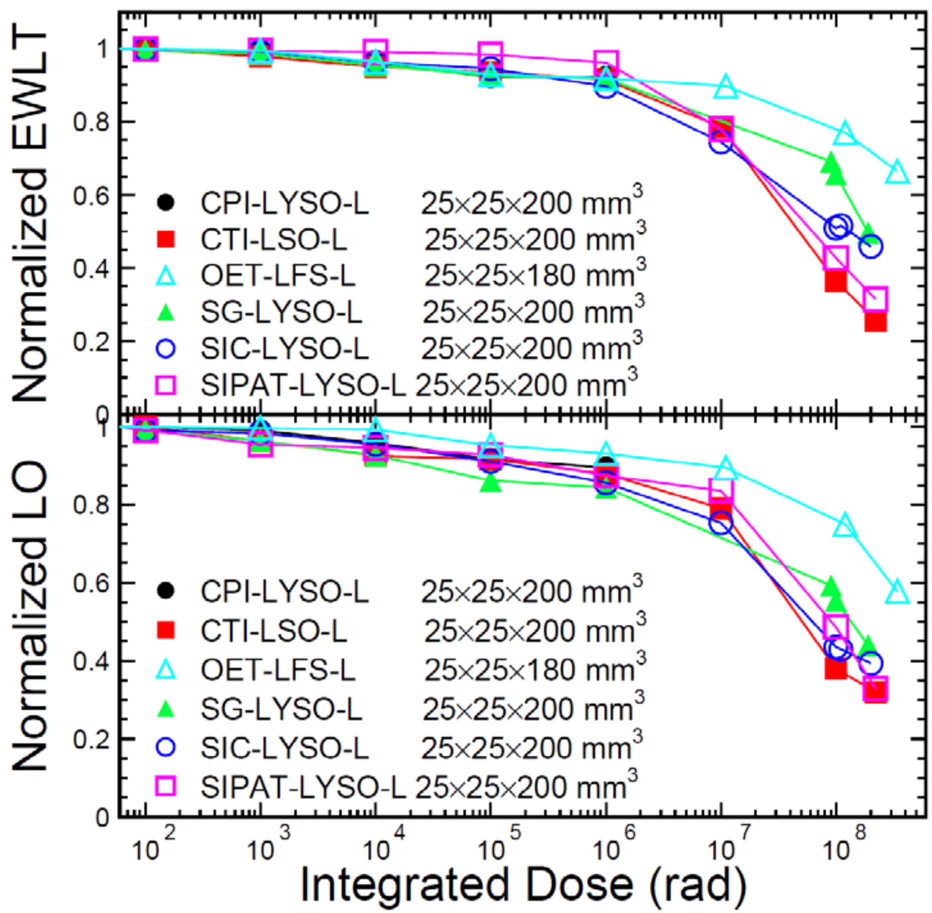
$$\mathrm{RIAC} = \frac{1}{l}\ln\frac{T_0(\lambda)}{\mathrm{T}(\lambda)}$$

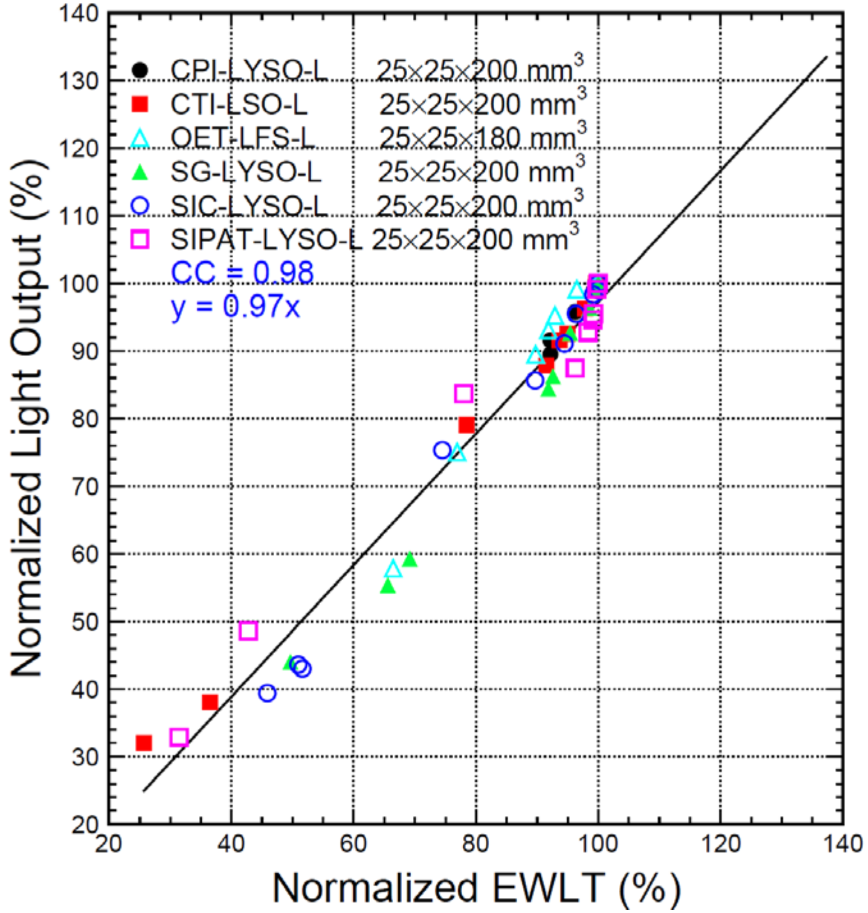
EWRIAC or emission weighted radiation induced absorption coefficient is defined as:

$$\mathrm{EW}RIAC = \frac{\int RIAC(\lambda)\mathrm{Em}(\lambda)d\lambda}{\int \mathrm{Em}(\lambda)d\lambda}$$

LYSO/LSO/LFS: Normalized EWLT and LO vs. Dose and LO vs. EWLT

The best sample: 58% light output after 340 Mrad

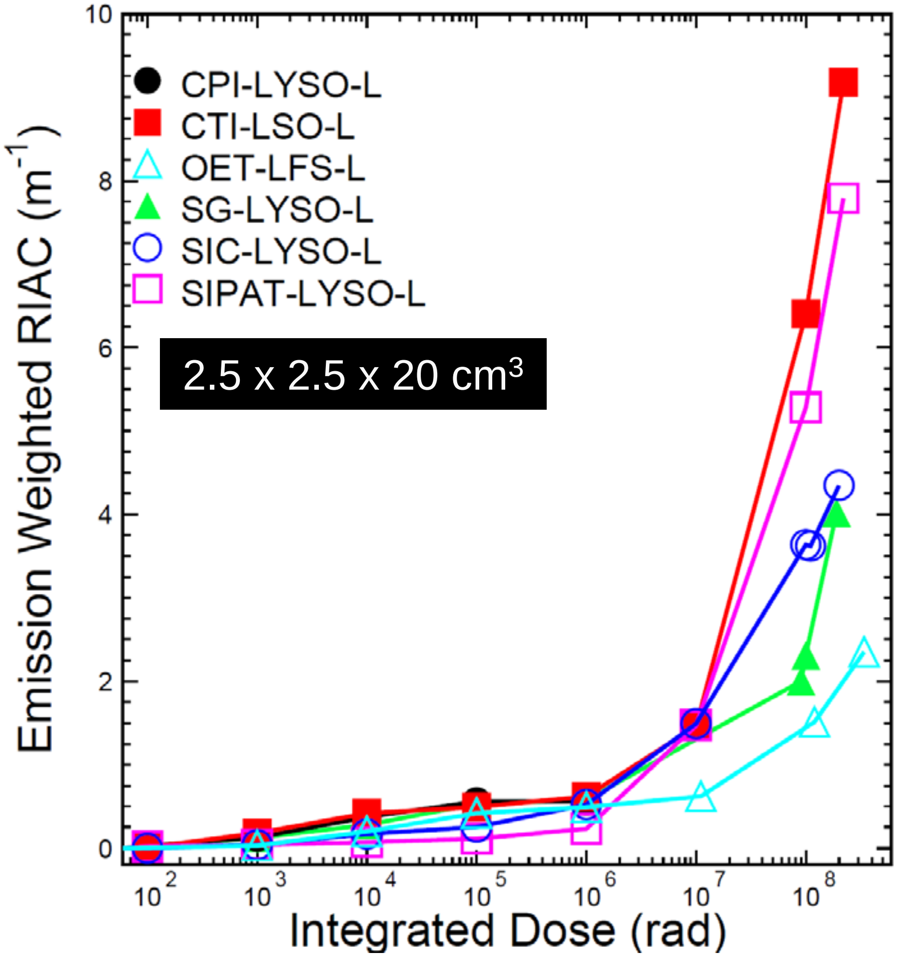


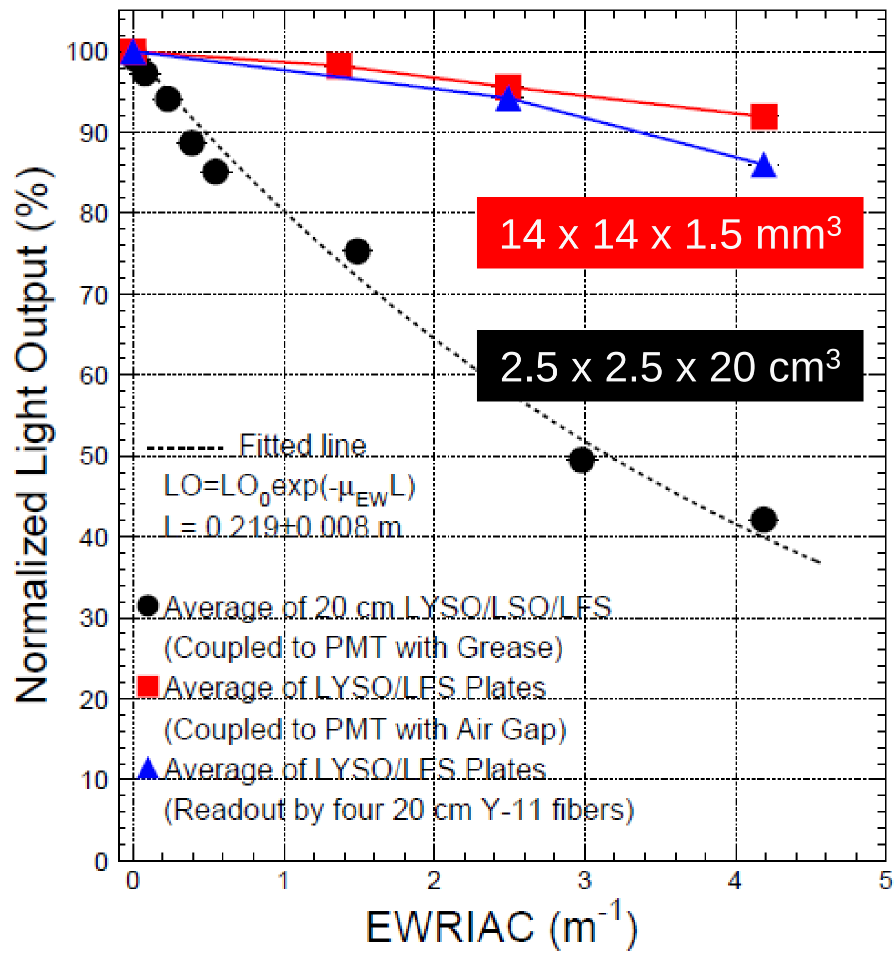


Good correlation between LO and EWLT: LO loss is caused by absorption

LYSO/LSO/LFS: EWRIAC vs. Dose and Normalized LO vs. EWRIAC

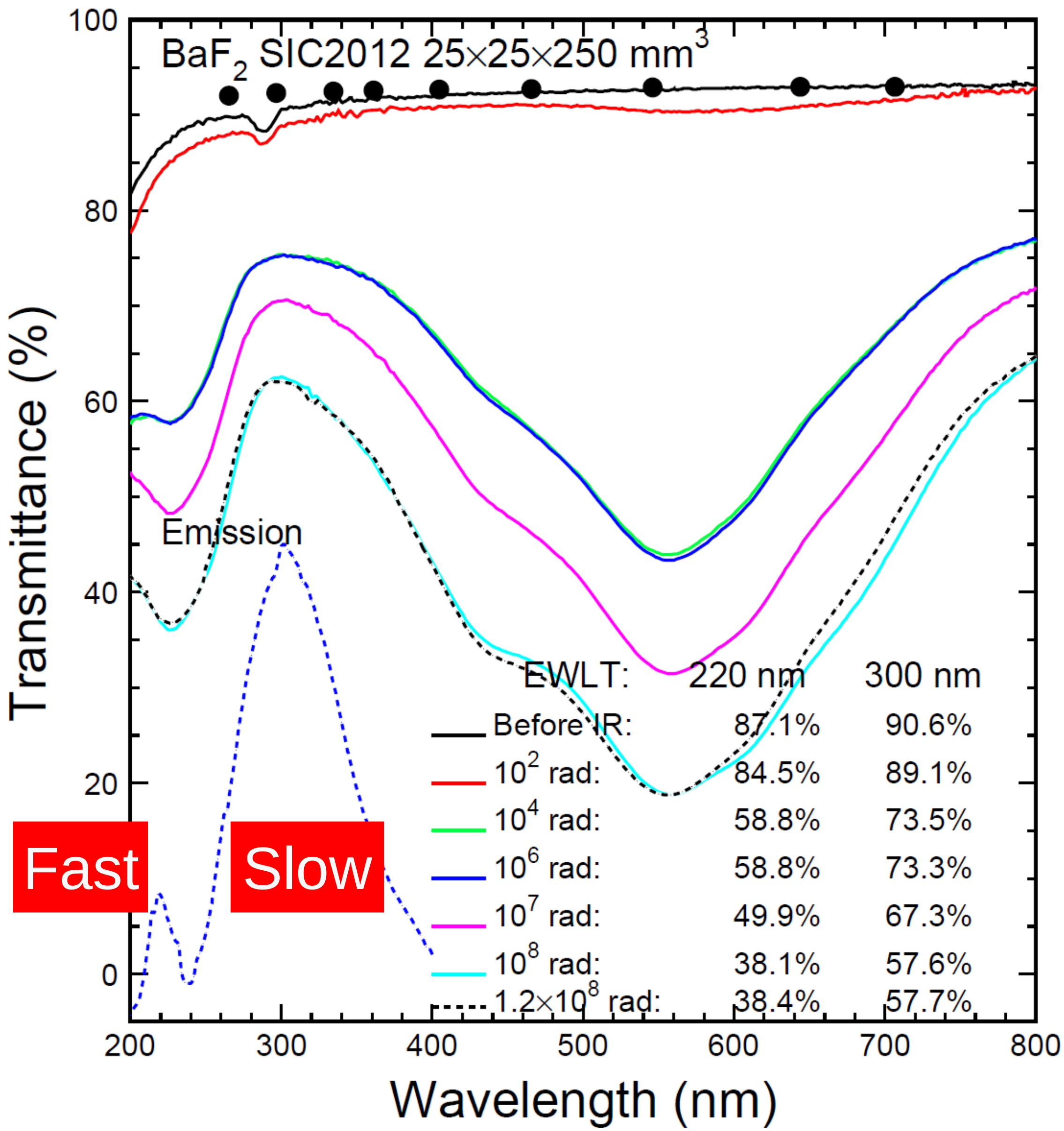
EWRIAC in the best sample is 0.62, 1.5 and 2.4 m^{-1} after 10, 120 and 340 Mrad





With EWRIAC of 3 m^{-1}, LO losses in 14x14x1.5 mm plates and 20 cm long crystals are 5%/8% for direct/WLS readout and 50%

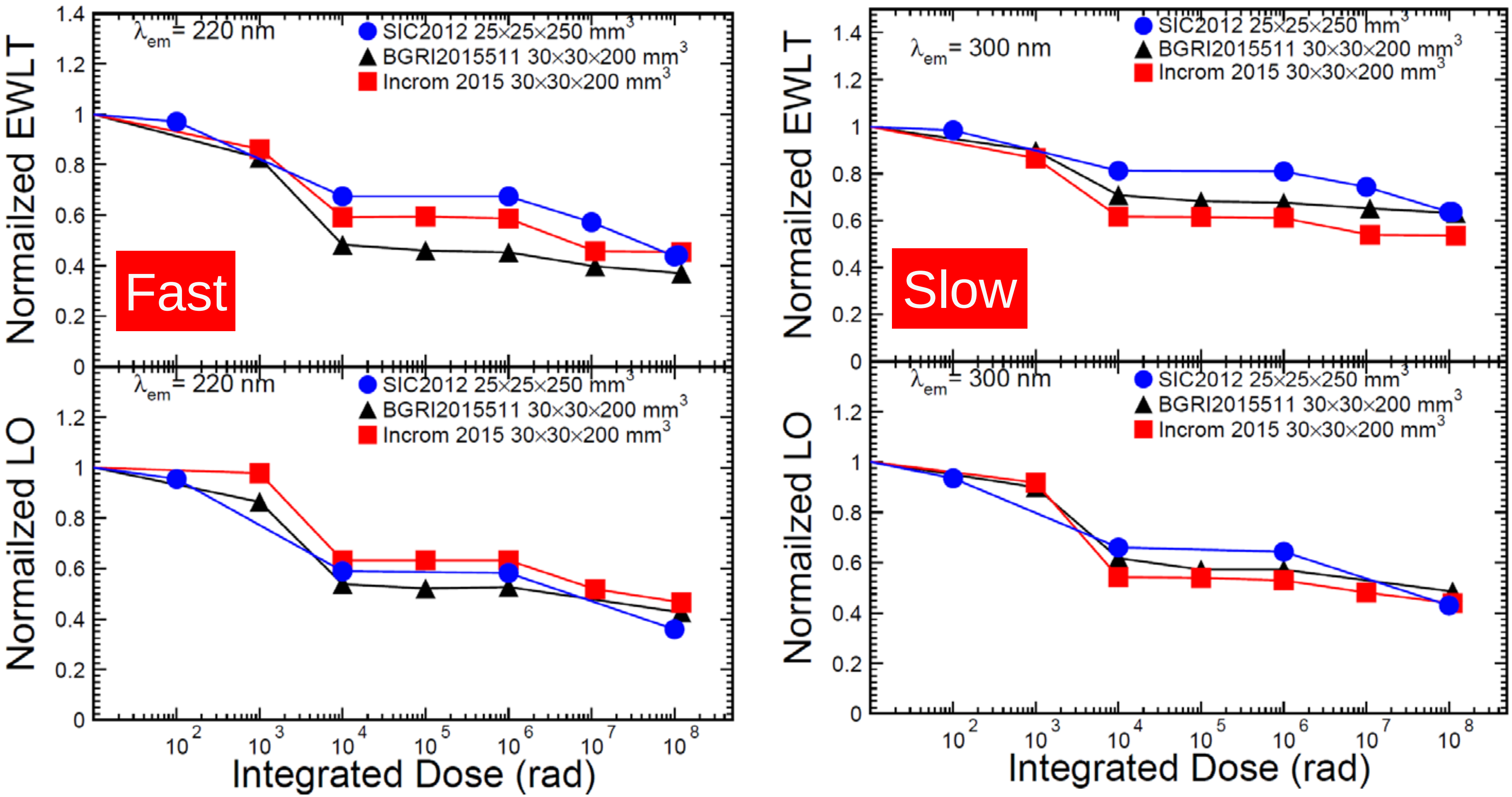
BaF_2: Longitudinal Transmittance



Transmittance damage: 44% and 64% EWLT for the fast and slow scintillation component respectively after 120 Mrad

BaF_2: Normalized EWLT and LO

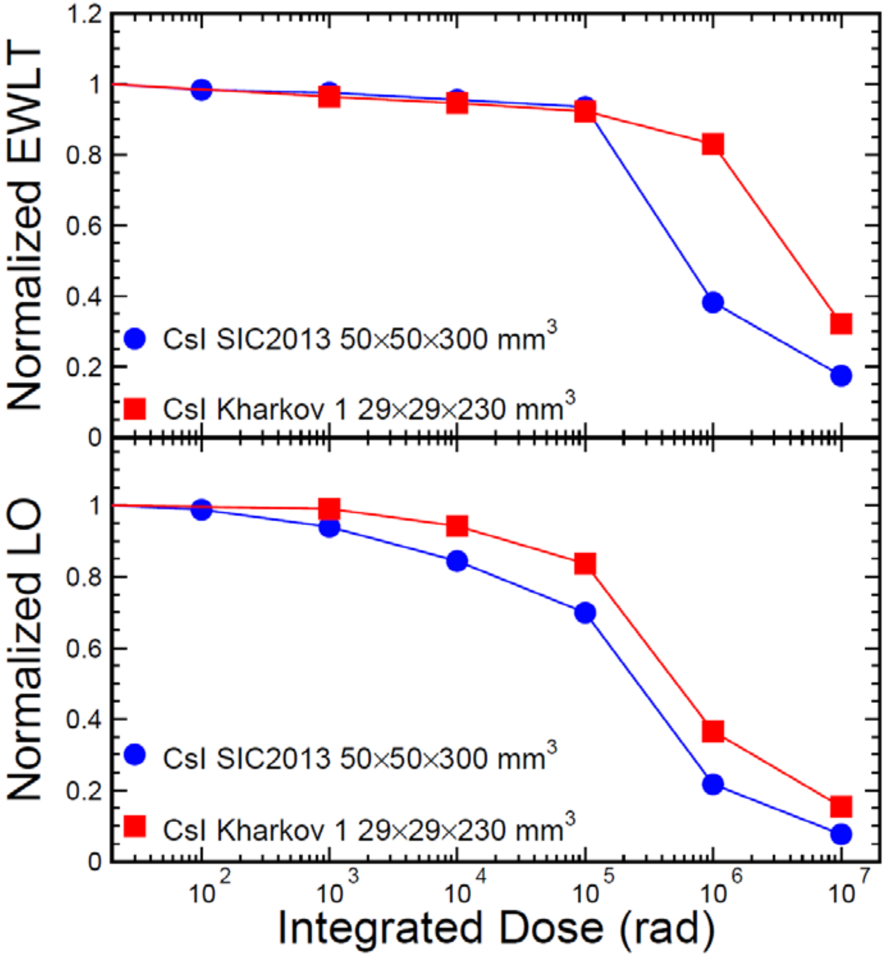
Consistent damage in crystals from three vendors

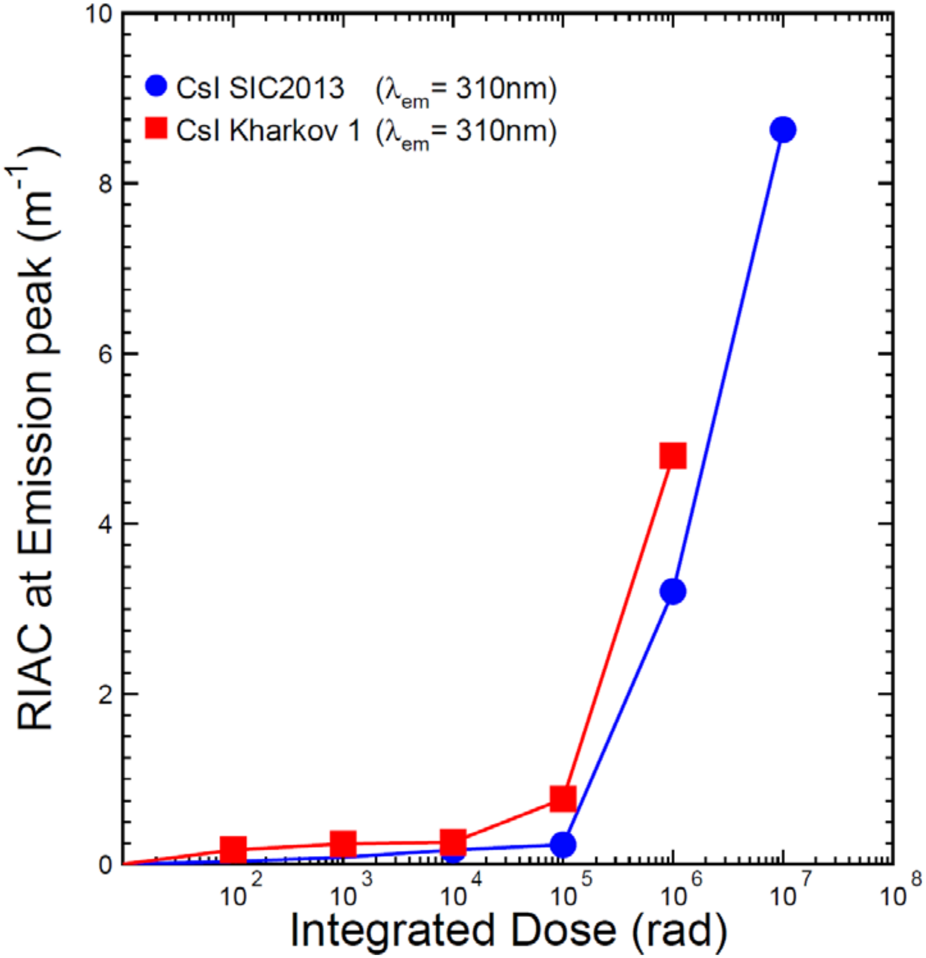


40%/45% LO for the fast/slow component after 120 Mrad

Pure CsI: Normalized EWLT/LO and RIAC @ Emission Peak

Consistent damage in crystals from two vendors

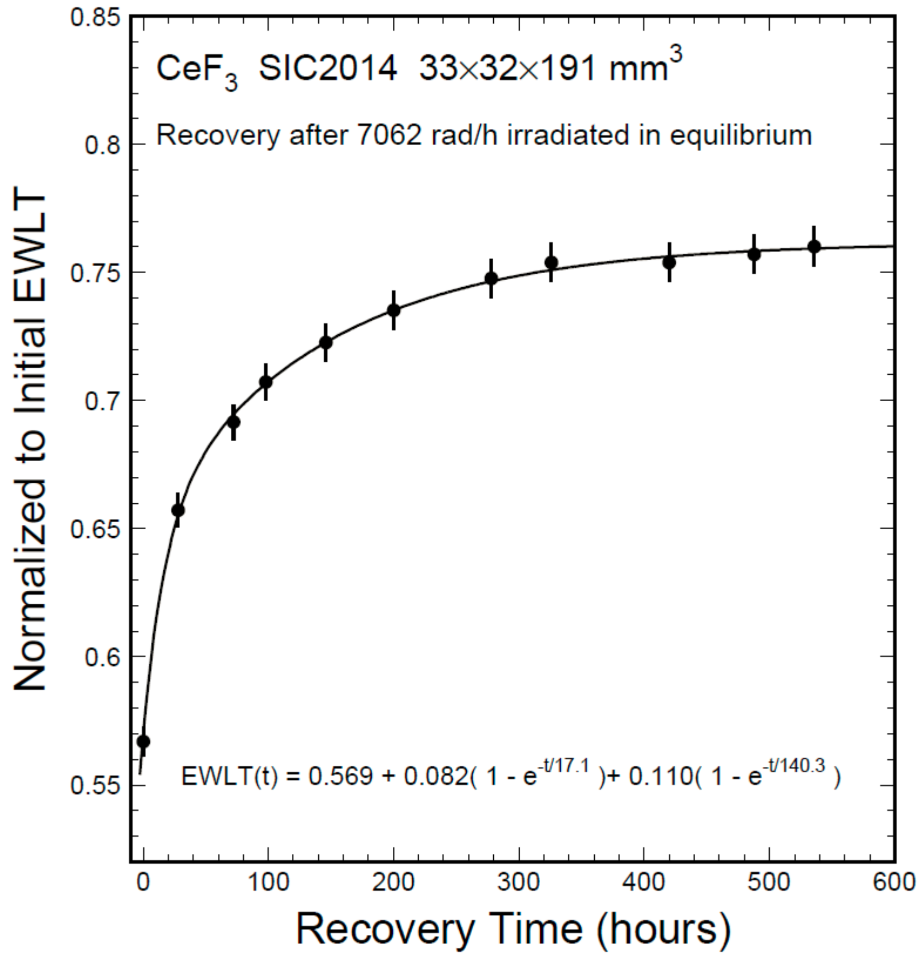


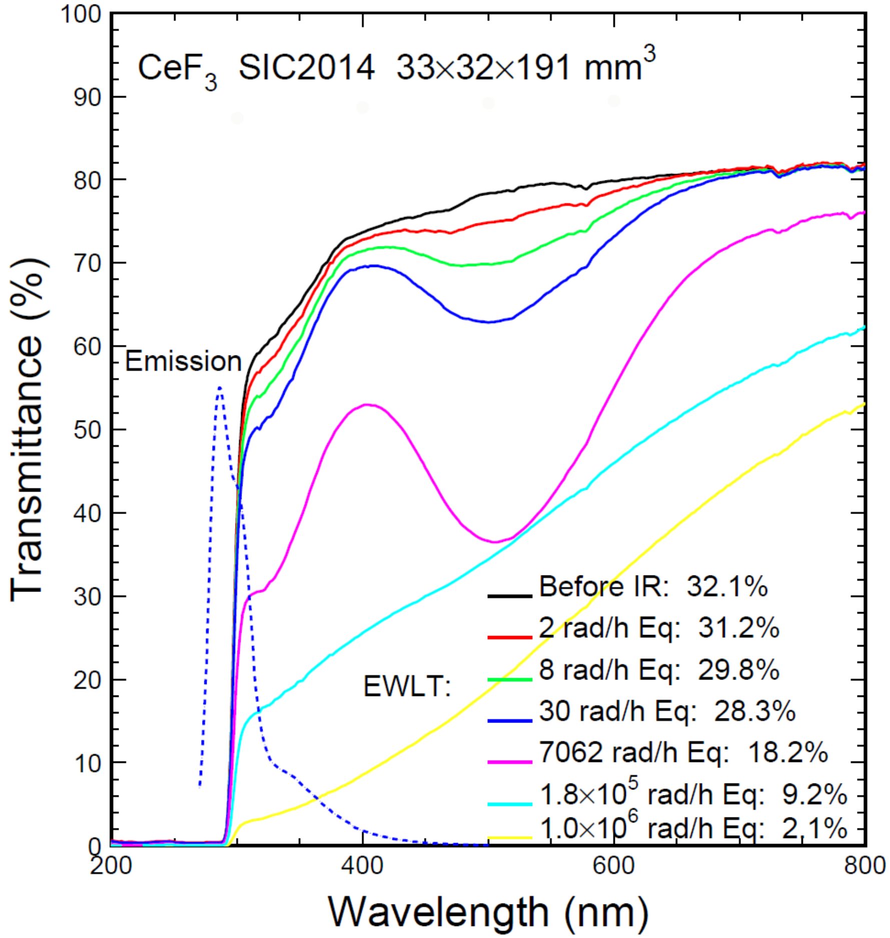


No significant damage in LO up to 100 krad

CeF_3: Damage & Recovery

Damage in CeF_3 recovers at room temperature, so is dose rate dependent

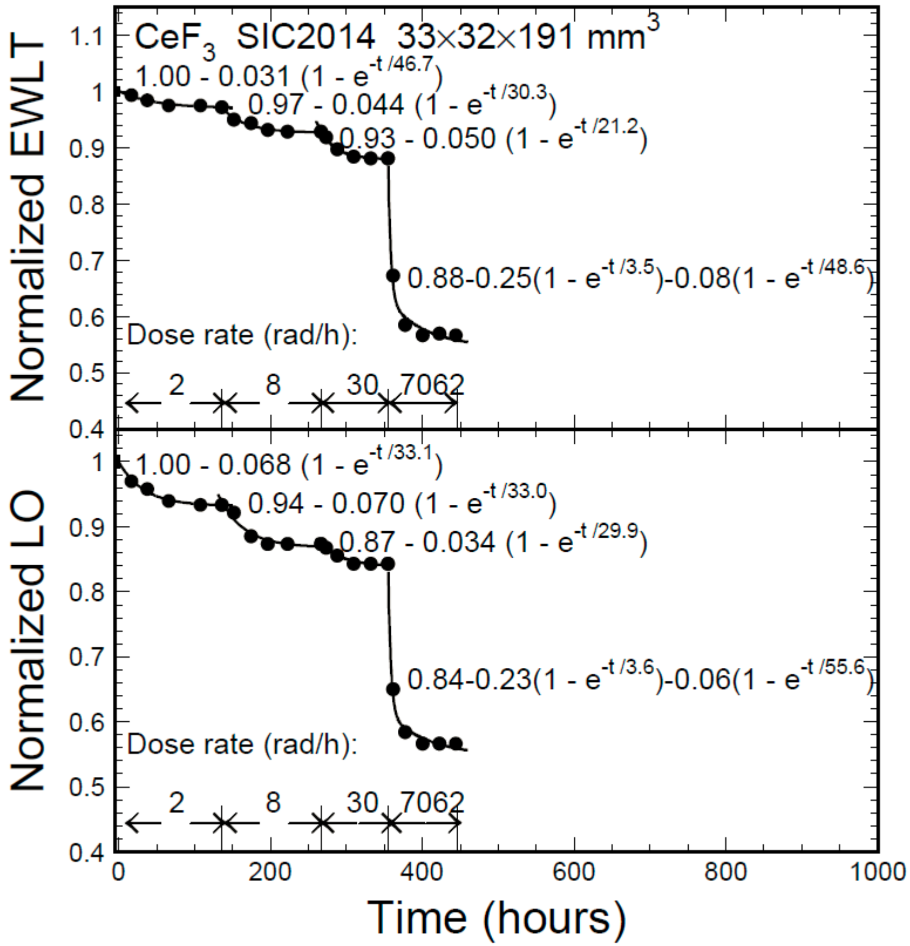


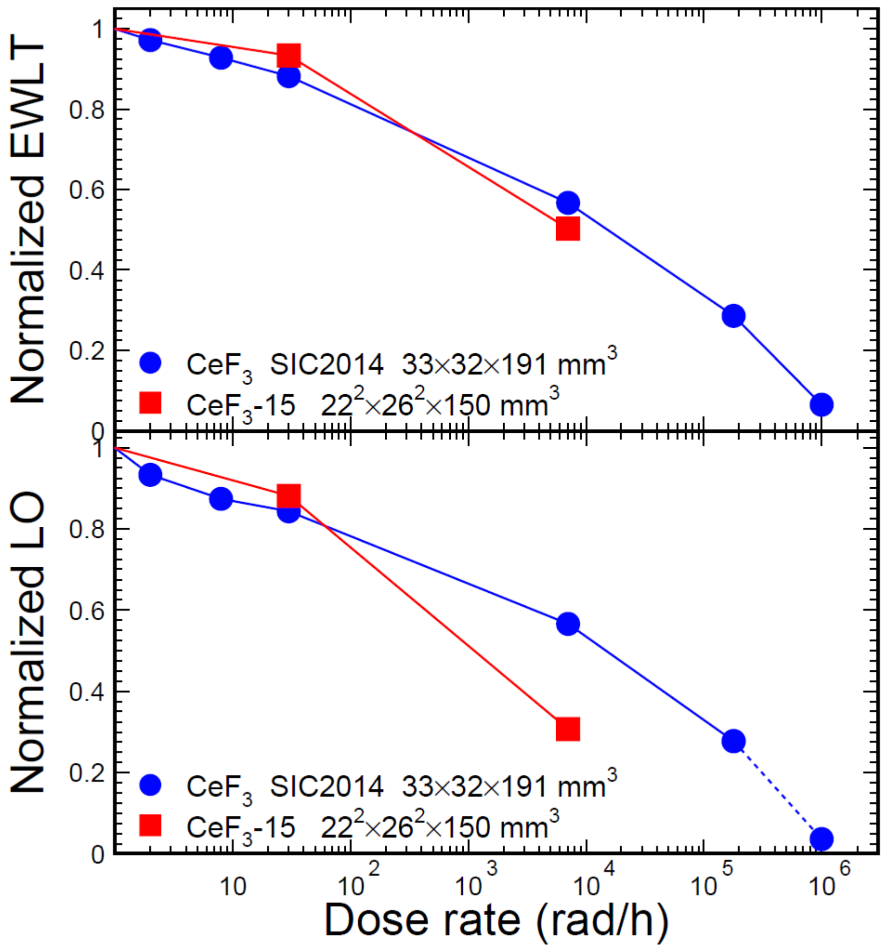


Radiation damage in BGO and PWO is also dose rate dependent

CeF_3: Normalized EWLT and LO

Irradiation carried out under a dose rate until reaching equilibrium
Dose rate dependent damage observed in both EWLT and LO

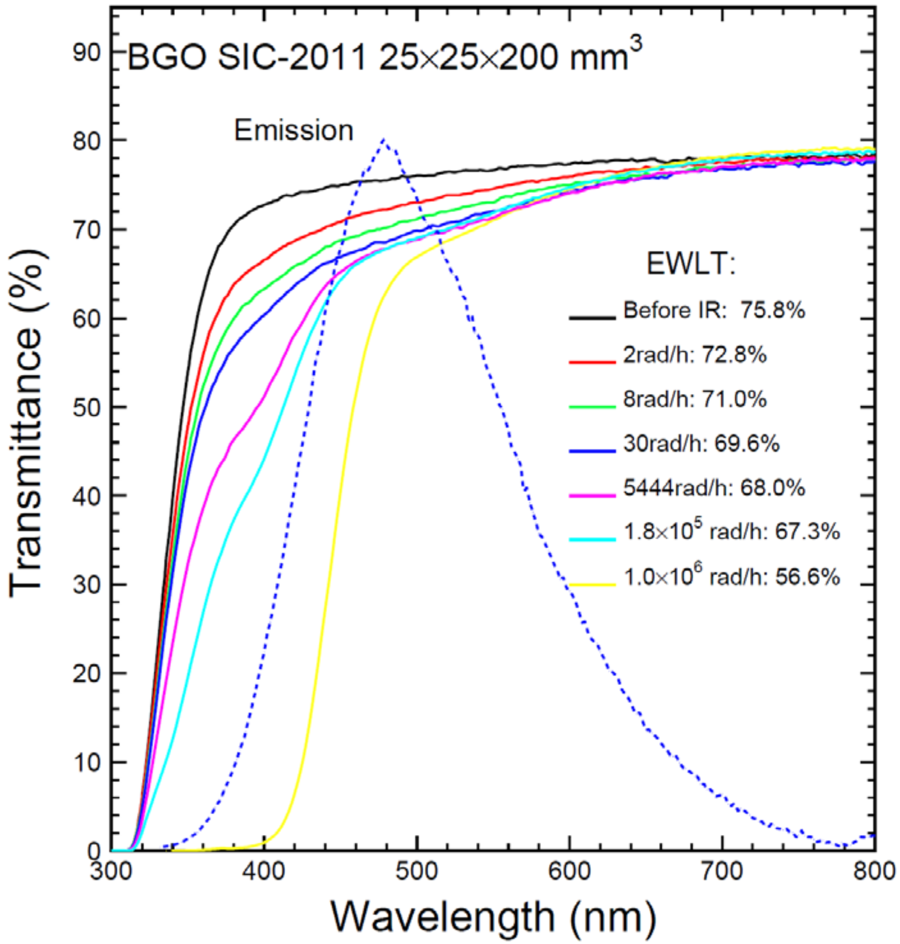


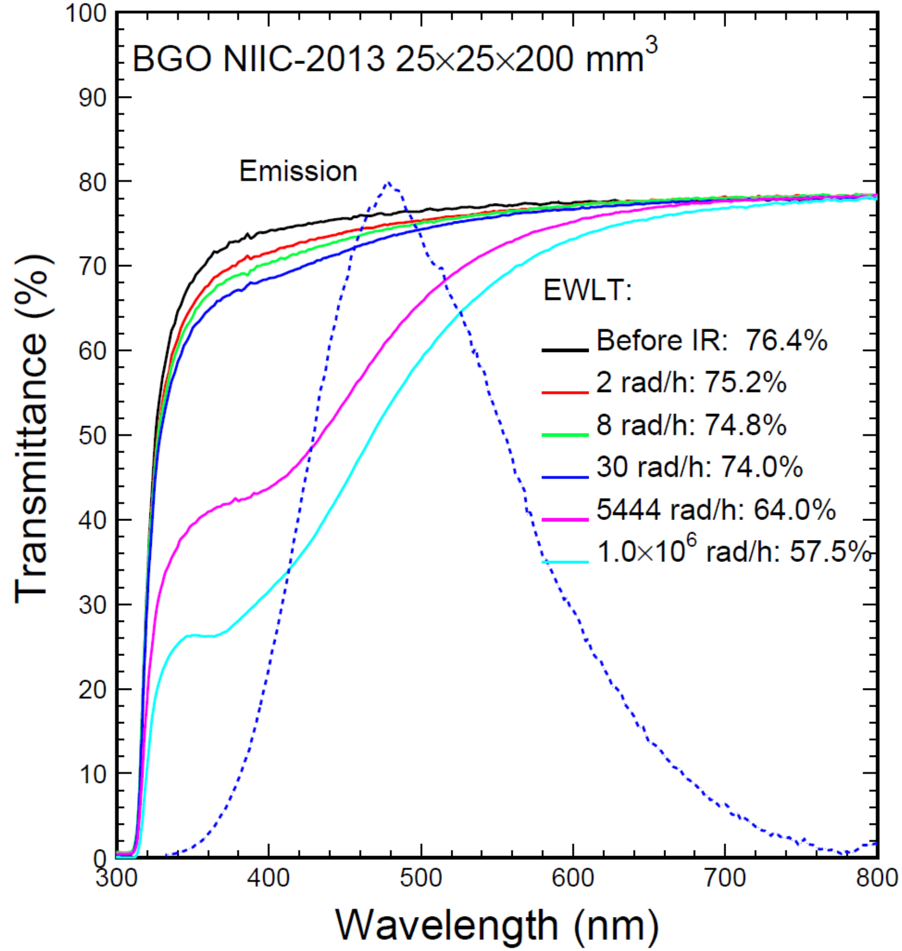


LO is too low to be measured under 1 Mrad/h in equilibrium

BGO: Longitudinal Transmittance

Dose rate dependent damage in crystals from two vendors

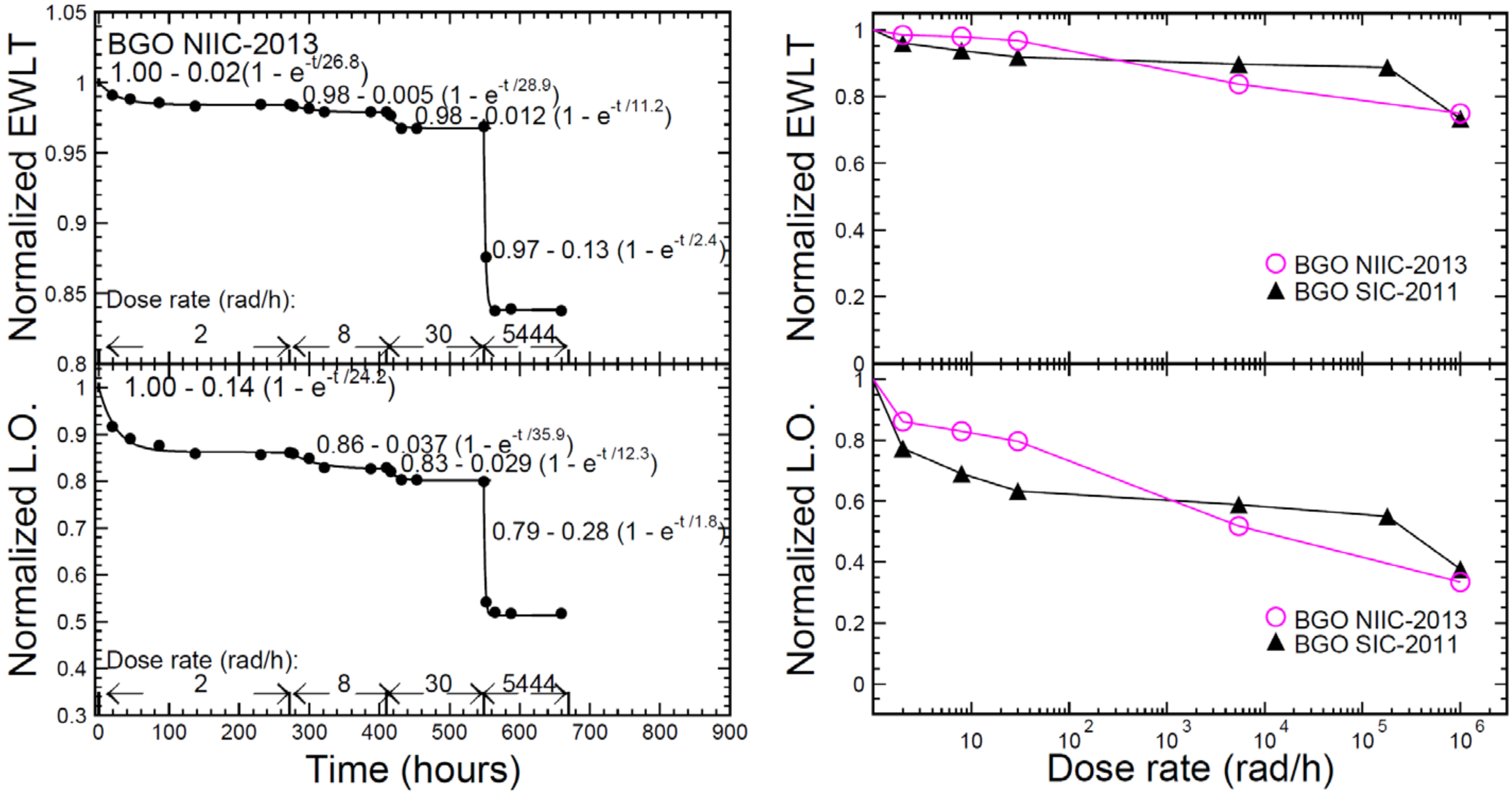




75% EWLT under 1 Mrad/h

BGO: Normalized EWLT and LO

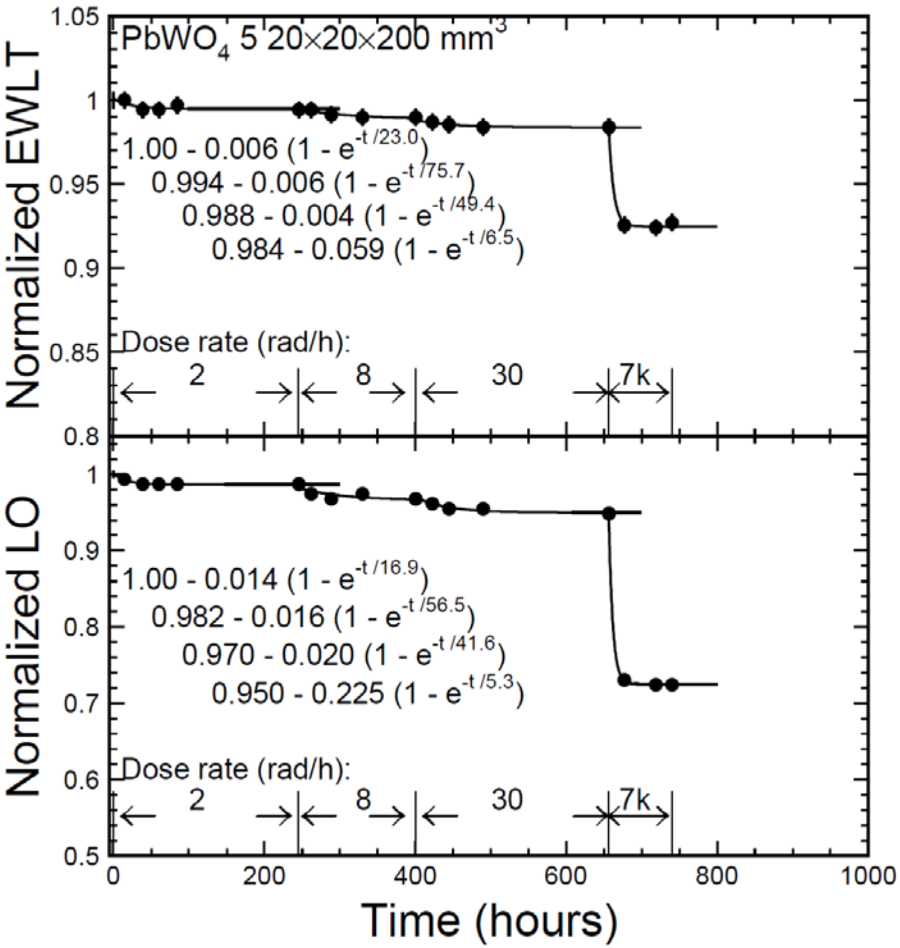
Dose rate dependent damage observed in both EWLT and LO

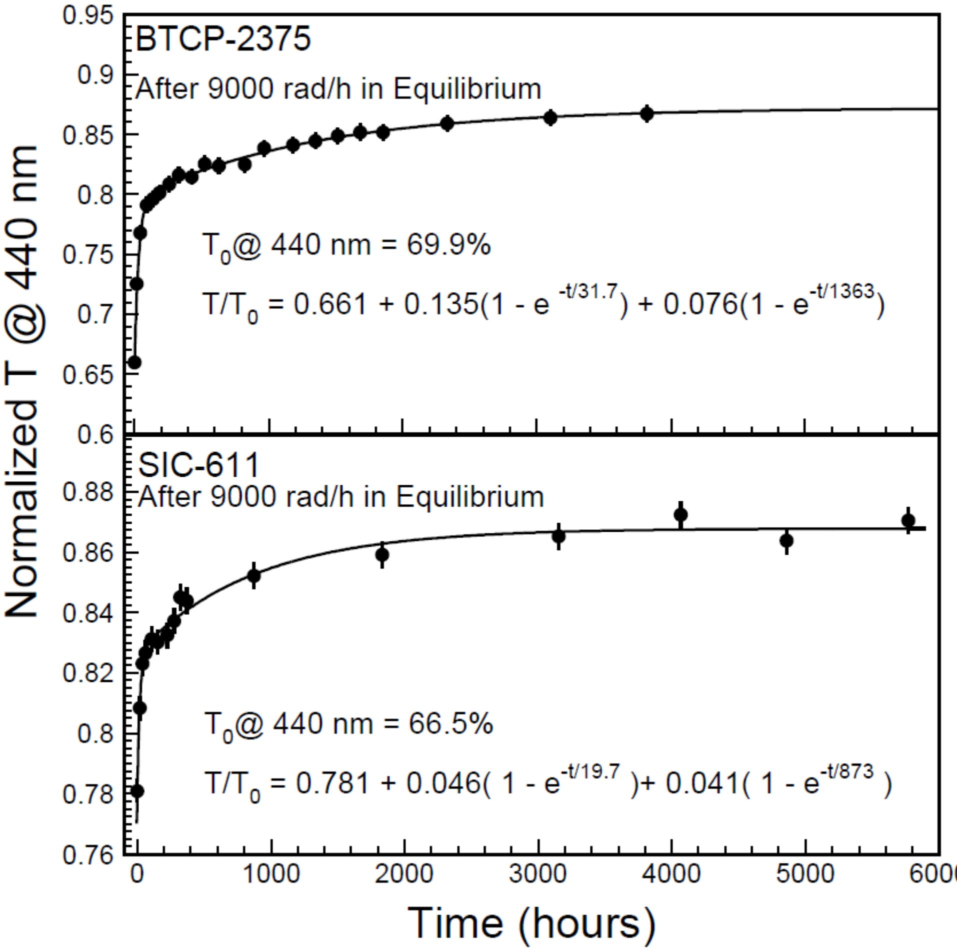


35% light output under 1 Mrad/h for both vendors

PWO : Damage & Recovery

Dose rate dependent damage observed in both EWLT and LO

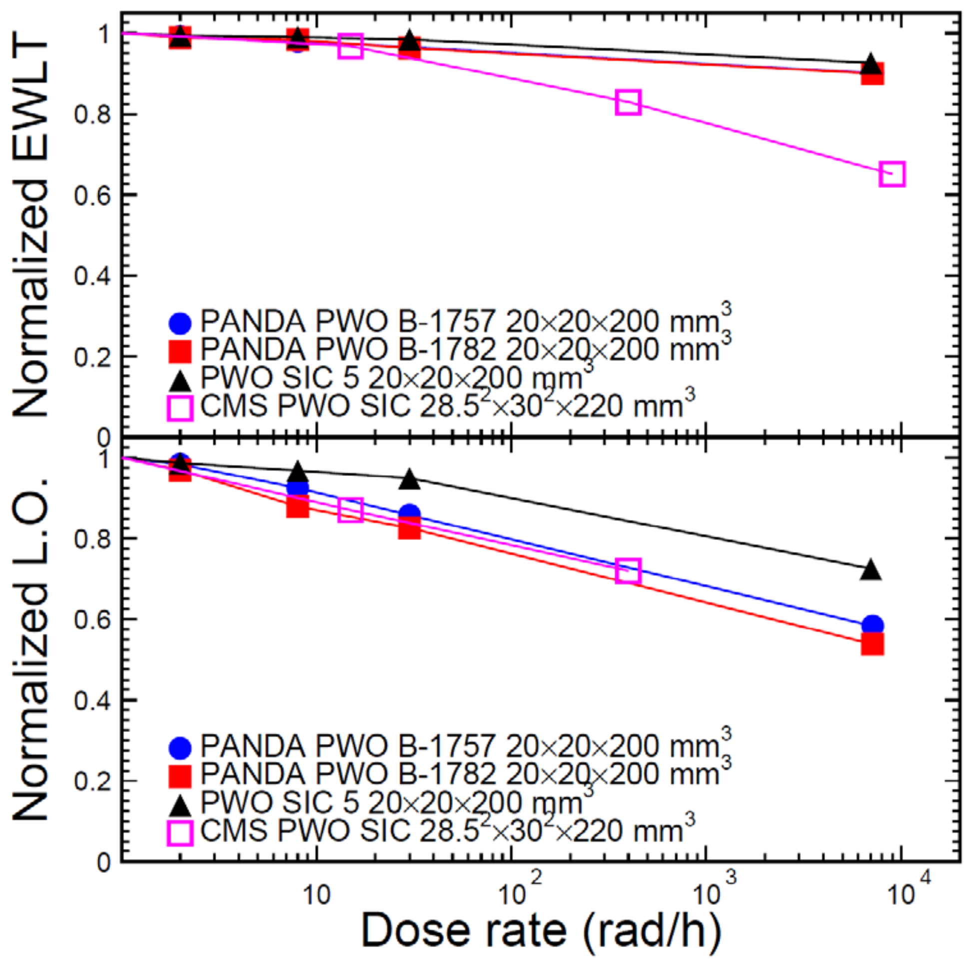


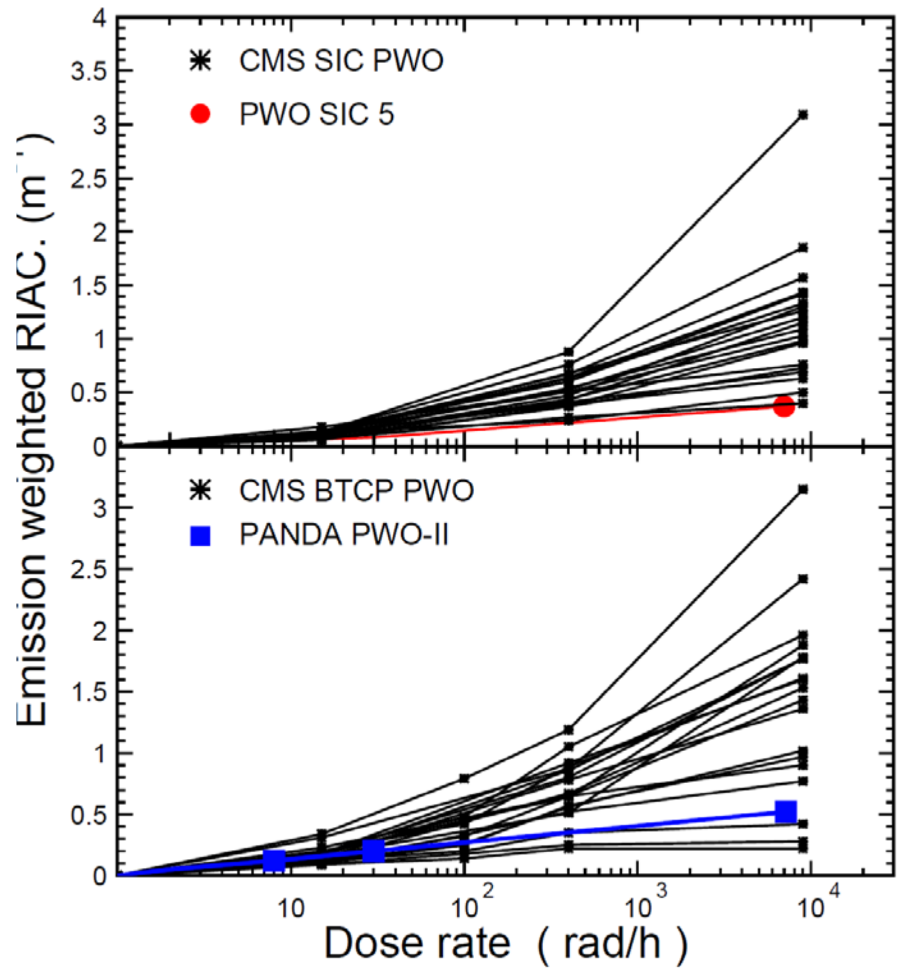


Recovery is not complete because of deep color centers

PWO: Normalized EWLT/LO and EWRIAC vs. Dose Rate

Damage in PWO crystals is diverse, so quality control is important

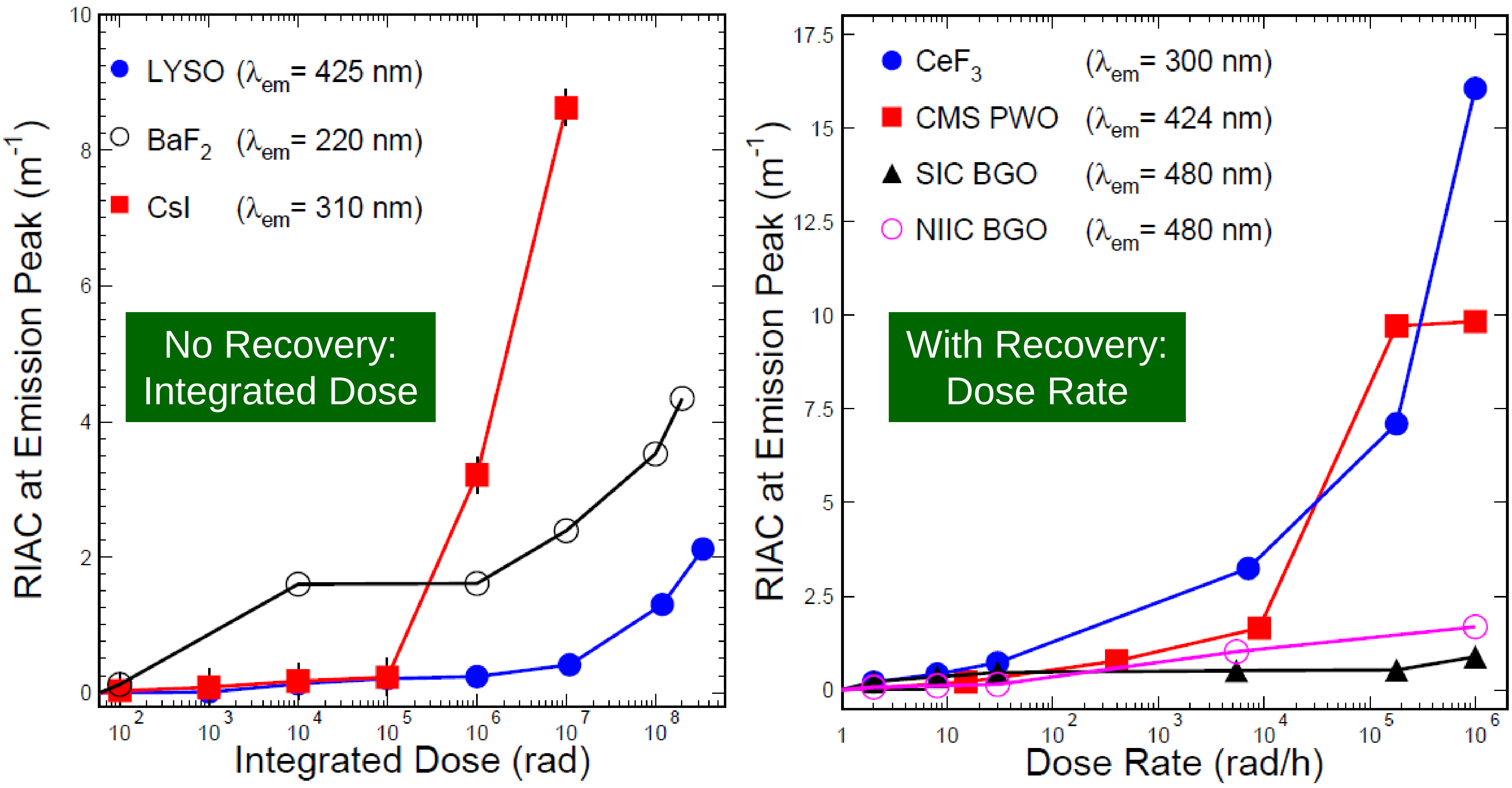




PWO-II for Panda and PWO 5 for JLAB are better than CMS PWO

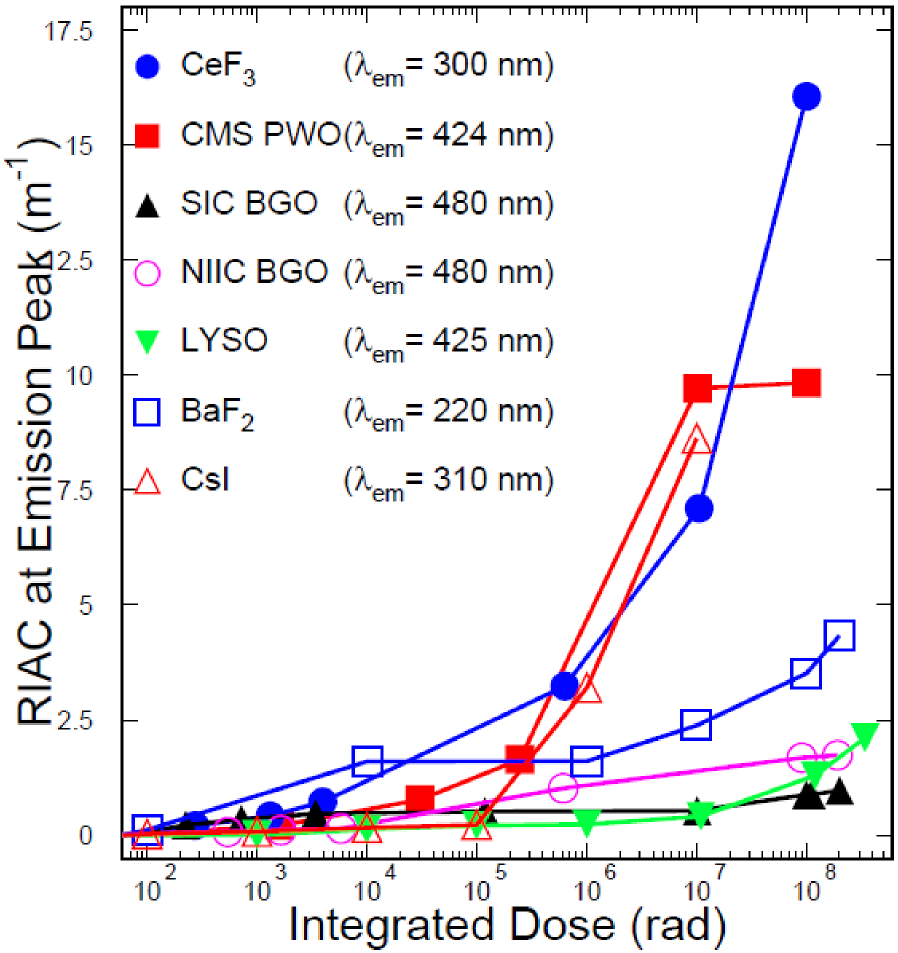
All Crystals: RIAC @ Emission Peak

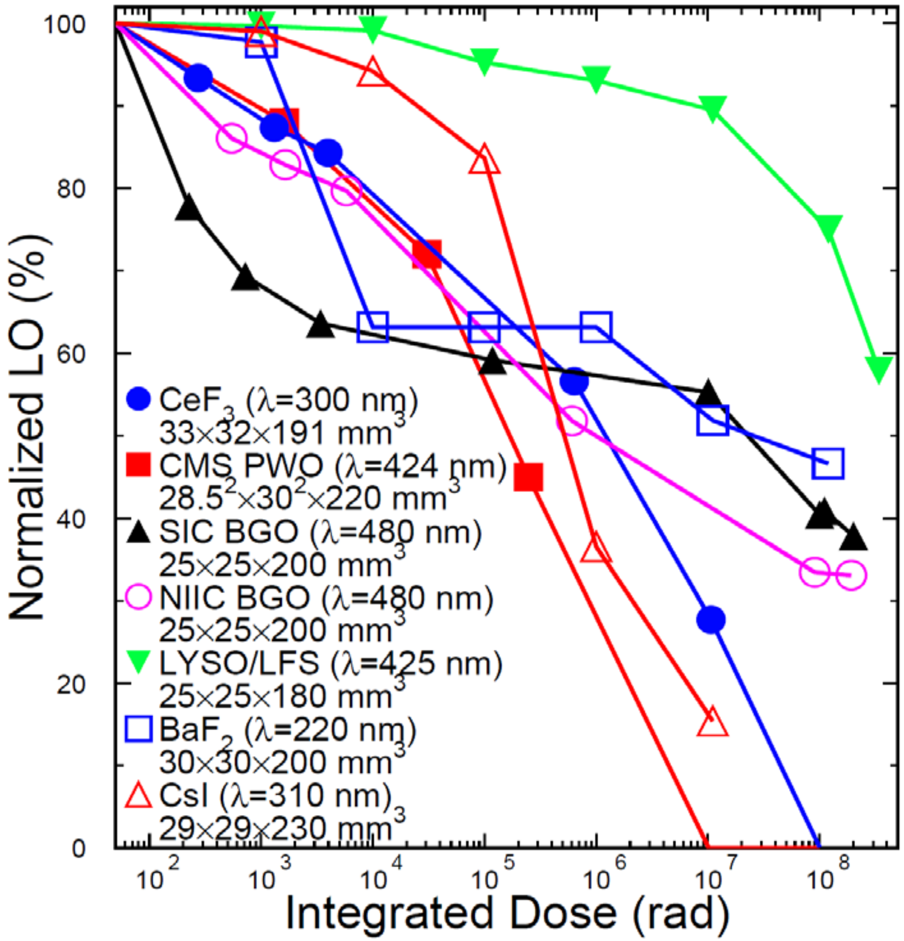
Pure CsI is good below 100 krad; LYSO and BaF_2 are good beyond 1 Mrad
BGO shows small radiation induced absorption up to 1 Mrad/h



All Crystals: RIAC and LO

Ignoring dose rate dependence, the values of RIAC at the emission peak and normalized LO shown as a function of the integrated dose





LYSO crystals show the best radiation hardness up to 340 Mrad

Summary

- Gamma-ray induced damage in various scintillating crystals of about 20 cm long was investigated up to 340 Mrad.
- Damage in LYSO/LSO/LFS crystals from six vendors was measured. The best sample shows 58% light output after 340 Mrad.
- Damage in BaF_2 crystals from three vendors is consistent. 40%/45% LO is observed after 120 Mrad for the fast/slow component.
- Damage in pure CsI crystals from two vendors is consistent. Good radiation hardness is observed below 100 krad.
- Damage in CeF_3, BGO and PWO recovers at room temperature, so is dose rate dependent. The quality of the large size CeF_3 crystals grown 20 years ago is worse than PWO and BGO.
- Damage in BGO crystals from two vendors was measured. 35% light output is observed in both crystals under a dose rate of 1 Mrad/h.
- Damage in PWO crystals is diverse. Two PWO-II crystals for Panda and one PWO 5 crystal for JLAB are better than CMS PWO.
- LYSO/LSO/LFS crystals show the best radiation hardness among all scintillation crystals up to 340 Mrad.